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13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking General Physics Institute as follows: The contractor will investigate the possibility of producing a laser operating on 589 nm with 10-40 Watts output power based upon frequency doubling of a LiF crystal with F_2^- color-centers as detailed in the proposal.

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Laser with Wavelength 0.589 μm ("Sodium Wavelength Laser")

Contract F61708-97-W0127

Final report.

1. Introduction

The goal of the research is elaboration of concepts and ideas which lead to the development of a laser system which produces 10 to 40 watt average output power radiation at 0.589 μm.

In the present study we have evaluated both theoretically and experimentally the possibility to use radiation from a F_2^- colour centres (cc) laser in LiF crystal with SHG in a non-linear crystal to reach this goal.

The tuning range of a LiF:F_2^- laser is 1.1 - 1.26 μm at room temperature [1]. The wavelength λ=1.178 μm (λ/2=0.589 μm) is situated close to the middle of the tuning range. In Fig.1 there are plotted absorption (*a*) and emission (*b*) cross sections of F_2^- - cc in LiF. To draw these curves we used data from [2, 3] and regarded the curves shape as Gaussian.

A large number of results concerning with F_2^- - cc lasers at room temperature have been obtained at pulse pumping. To show parameters of the LiF:F_2^- - lasers which have been achieved up to now we can refer to [2,4]. In [4] pump power threshold P_{th}=10 W has been reported at pump wavelength λ=1.047 μm and pulse duration 1 μs and that of 100 W at λ=1.064 μm, 0.2 μs. It should be also mentioned the outstanding result [5] (P_{th}=2.3 W for the cw mode of LiF:F_2^- laser), which have not been repeated up to now. As we see pump power threshold at λ=1.064 μm is high so we should to find conditions to lower the threshold.

The laser oscillation quenching has been observed in the first works [1,5,6] devoted LiF:F_2^- laser at pumping by high repetition rate or cw YAG:Nd^{3+} - lasers and as it has been shown in the works implementation of a chopper enabled to restore oscillation. The authors of the cited works has explained the phenomena by thermal lens which arose in LiF under pump radiation and resulted in laser oscillation quenching. In [6] special construction of resonator has been implemented to solve the problem. We should take into account this problem when constructing the LiF:F_2^- - generator for "sodium wavelength laser" too.

In our study we followed the tasks as they were formulated in the Proposal.

Task 1. Development of a YAG:Nd 1.06 μm Q-switched laser with pulse duration of 10 - 50 ns for pumping LiF: F_2^- crystals.

Task 2. Development of a laser on LiF: F_2^- crystals at wavelength 1.178 μm with wide spectrum width at pumping by the neodymium laser (see Task 1).

Task 3. Modification of the YAG:Nd laser to obtain radiation at 1.06 μm with pulse duration of 100 μs at repetition rate of 1 kHz The using of this laser to obtain generation in LiF: F_2^- crystals at 1.178 μm.

Task 4. Experiments on second harmonic generation.Theoretical investigation of a possibility to obtain high average output power radiation at 589 nm. Prepare final report.

Here are the results of our investigation below.

2. Characteristics of a LiF:F_2^- laser

We have studied LiF:F_2^- - laser characteristics for two quite different pump pulse duration: 50 - 100 ns (short pulse pumping) and 100 μs (long pulse pumping).

2.1. Short pulse pumping

For pumping LiF:F_2^- laser we have made a YAG:Nd^{3+} laser with LiF:F_2^- crystal passive Q-switch. Fig. 2 represents the laser layout. This is the base scheme of our YAG:Nd^{3+} laser. During our study we changed some parts of the scheme in according with solving tasks. We point out what changes were made in appropriate parts of this text. Numbers in Fig. 2 denote: 1, 2 are resonator mirrors; 3 - LiF:F_2^- crystal passive Q-switch; 4 - 3.5 mm diaphragm for TEM_{00} - mode selection; 5 - ∅5/75 mm YAG:Nd^{3+} laser rod; 6 -glass plane parallel plate at Brewster angle. The resonator length was 113 cm. Mirror 1 had reflectivity R=100% at λ=1.064 μm and radius of curvature r=∞. Output mirror 2 was a glass plane parallel plate. The passive Q-switch had weak signal transmission T_0=25 % and transmission at high power signal T_1=75 %, at wavelength 1.064 μm. In some experiments passive Q-switch had other characteristics that is: T_0=65 % , T_1=85 %. Here is the laser characteristics.

Output energy	30 mJ (T_0=25 %),
	10 - 15 mJ (T_0=65 %)
Pulse duration	25 - 30 ns (T_0=25 %),
	80 - 100 ns (T_0=65 %)
Pulse repetition rate	up to 5 Hz
Output beam profile	close to TEM_{00}

Fig. 3 represents an oscillogram of output pulse. It was recorded by photodiode with time resolution about 1 ns and Tektronix TDS 744A digitizing oscilloscope. One can clear see longitude mode beating in Fig. 3. For our aims it is not important.

Fig. 4 represents transverse distribution of the output beam energy at a plane positioned at distance 20 cm off output mirror. The distribution was obtained by scanning 0.1

mm slit across the output beam and by measuring the energy passed through the slit. In Fig. 3 dots are experimental points, solid curve is the best fit of the experimental data by function $E(y) = \exp(-2 \cdot \frac{y^2}{w^2})$, where y is transverse coordinate and w=1.08 mm.

Fig. 5 represents the experiment layout of LiF: F_2^- laser which have been pumped by the YAG:Nd^{3+} laser. Pumping scheme was uncollinear. Numbers in Fig. 5 denote: 1 - YAG:Nd^{3+} laser; 2 - filters; 3 - mirror with high reflectivity at 1.064 μm; 4 - lens with focal length 85 cm; 5 - 90° prism for alignment pumping beam; 6, 10 - mirrors of LiF: F_2^- - laser, mirror 6 had radius of curvature $r_2=\infty$ and reflectivity R_2=100 %, mirror 8 - r_1=300 cm, R_1=70% at wavelength 1.178 μm; 7 - two prisms for wavelength selection; 8 - lens with focal length 106 cm, the lens was situated at distance 91 cm from mirror 10; 9 - LiF: F_2^- - crystal active element which had weak signal transmission T_0=14 % and transmission at high power T_1=80 %, at wavelength 1.064 μm;. Length of the LiF: F_2^- - active element was 6 cm. Distance between mirrors 6 and 10 was 108 cm ±1.5 cm. The crystal was situated at distance 3 cm from mirror 10.; 11 - 90° prisms; 12 - fast photodiode (for monitoring pump beam) or He-Ne - laser (for alignment of the laser system); 13 - Si-photodiode for measurement pump beam energy. For measurement output pulse energy of LiF: F_2^- laser we used calibrated (mJ/V) Ge-photodiode. Passive Q-switch in YAG:Nd^{3+} - laser had initial transmission 65%.

Our laser system worked in the next way. Pump beam (λ=1.064 μm) from laser 1 was divided by mirror 3. One part of the beam pumped LiF: F_2^- laser active element (AE) 9 after passing through focusing lens 4 and prism 5. Angle between axis of LiF: F_2^- laser resonator and pump beam inside AE was about 0.5° . Pump beam transverse distribution diameter was $4w_p$=0.7 - 0.8 mm at place of AE and at energy density level 13% from the maximum of the distribution. The other part of the beam which passed through mirror 3 was used for measurement of pump beam energy. Filters 2 was used for attenuation of pump beam energy. Polarisation of the pump beam at output laser 1 and at place of AE was linear. Calculations show that TEM_{00} - mode has w_g =0.3 mm at mirror 10 and diameter $4w_g$=1.2 mm (see above) so $w_p \approx w_g$.

Fig. 6 represents both pump (*a*) and output (*b*) oscilloscope traces. Duration of the pumping (T_p=75 ns) and the generation (T_g=60 - 70 ns) pulses were close to each other. Fig. 7 shows output energy (W) as function of pump pulse energy (E_p) which has been changed by filters 2 (see Fig.5). The slope efficiency is 10.7 %, threshold energy is 0.56 mJ, overall

efficiency 9.4%. Fig. 8 represents generation spectrum. It was recorded by monochromator MDR-12 and Ge-photodiode which has constant sensitivity in this spectral region. Spectrum width was 3.2 nm. Maximum was close to 1.178 μm.

2.2. Long pulse pump

During our work we've come to conclusion that there is lens in the LiF: F_2^- which arise when active element is under pump radiation. This conclusion follows from the fact that in the resonator composed by flat mirror and mirror with radius of curvature 25 cm (LiF: F_2^- is situated close to flat mirror and pumped through this mirror) threshold is achieved for lengths of the resonator L from 13 cm (minimum possible in our conditions) up to 43 cm. Pump pulse duration was 100 ns, pump beam diameter in the LiF: F_2^- was 800 μm. There is no radiation of generation in LiF: F_2^- crystal at threshold (λ=1.18 μm) so this lens is only due to pumping. The lens focal length f have to be positive (otherwise resonator will be unstable for L>25 cm) and processing the data gives us estimation for $f \approx +20 \div +30$ cm. Unlikely that the lens is due to thermal heating of the crystal because: a) pump rate is very low (single pulses), b) the lens bild up time is short (less than 10 ns) so the crystal density is constant (no thermal expansion). It is possible that the lens is due to change of lower and upper laser levels population of F_2^- - colour centres, but our calculation shows that the focal length have to be negative in this case. This is quite new phenomenon and further studies are needed to clear the question.

Fig. 9 presents the experiment layout for long pulse pumping. Numbers in Fig. 9 denote: 1 - YAG:Nd^{3+} laser; 2 - system of lens which was used to match pump beam spatial distribution and resonator TEM_{00} - mode; 3 - mirror with transmission 70 % at 1.064 μm and reflectivity 98 % at 1.18 μm, radius of curvature 6.5 cm; 4 - LiF: F_2^- - crystal active element which had weak signal transmission T_0=39 % and transmission at high power T_1=73 %, at wavelength 1.064 μm and transmission T_2=83 %, at wavelength 1.178 μm, length of the crystal was 2.5 cm, the crystal was placed in the middle of the laser resonator; 5 - resonator output mirror which had radius of curvature 6.5 cm and reflectivity about 95 % (in this case generation wavelength was λ=1.19 μm). The resonator length was 13 cm. As our calculation showed this resonator configuration has low sensitivity to lens focal length in the LiF:F_2^-.

Our long pulse pump experiments were aimed at determination of characteristics of LiF: F_2^- for the scheme of resonator (see Fig.9) and in particular at estimation of a threshold pump power. In Fig.10 there are pump (*a*) and output (*b*) oscilloscope traces at a free running

mode. Vertical axis are calibrated in kW. Calibration was made by measuring pump and output energy by a calorimeter and processing digital data from the oscilloscope. Fig. 11 shows output energy (W) as function of pump pulse energy (E_p). Experimental points in Fig.11 were obtained by attenuating pump beam by filters. One can clear see from Fig.10 *a, b* that pump and output powers change in time rapidly from low to high values. This mode of laser oscillation is far from steady state so it is difficult to evaluate effective pump and output pulse time duration from Fig.10 and consequently to estimate pump threshold from Fig.11. To find the threshold we approximated output power P_{out} as function of pump power P by the expression: $P_{out}(P,\eta,P_0) = \eta \cdot P - P_0$, where P is function of time (see Fig.10 *a*). Integration $E_p = \int P(t) \cdot dt$ gives us pump pulse energy. In the same way we find output energy $W(E_p,\eta,P_0) = \int (\eta \cdot P(t) - P_0) \cdot dt$. To determine values η and P_0 we minimise the function $F(\eta,P_0) = \sum_i (W_i - W(E_{pi},\eta,P_0))^2$,where E_{pi} and W_i are experimental pump and output pulse energies (see Fig.11), i=1..9. This procedure results in η=11.3%, P_0=8 W, and thereby threshold is P_{th}=72 W. Solid curve in Fig.11 is plotted by using this values η , P_0 and expression for $W(E_p,\eta,P_0)$ (see above).

One note should be made. Experimental points in Fig.11 were obtained by averaging pump and generation energy over several tens of shorts and at the same time calculated curve in Fig.11 were obtained by using the only one realisation which is represented in Fig.10 *a, b*. In justification it is possible to say: a) time pattern in Fig.10 is highly stochastic so it is possible to suggest that integration in time over oscilloscope trace is equal to averaging, b) processing of the other oscilloscope trace records (similar to that in Fig.11) gave us the same values of η , P_0.

3. Measurement of efficient cross sections of F_2^- - cc at 1.064 μm

For a proper calculation of output power of LiF: F_2^- laser as function of pump power, thermal heating of LiF under pump and generation radiation we should to know cross sections of absorption σ_a and emission σ_e. Comparing our experimental data (see Figs. 7 , 11) with results of calculation we've come to conclusion that the data depicted in Fig.1 should be checked.

To measure efficient absorption cross section we used the fact that transmission of LiF: F_2^- - crystal at wavelength 1.064 μm depends on energy density of incident radiation pulse. In Fig. 12 there is transmission of LiF: F_2^- - crystal as function of energy density (λ=1.064 μm,

pulse time duration was 15 ns). It is short pulse case because this time is about 4 times less then life time of F_2^- upper state [2]. Electric vector of light was parallel to direction [110] of LiF crystal. For calculation of transmission for a short pulse the expression was used

$$\frac{dx(z)}{dz} = -\alpha_1 \cdot (1 - e^{-x}) - \alpha_2 \cdot x, \qquad (1)$$

where α_1 is absorption coefficient of the centres, α_2 is due to passive losses (we assume that absorption from the exited state of a F_2^- - cc is absent), z is co-ordinate in the direction of propagation, x - normalised energy density $x(z)=E(z)/E_0$ and $E_0 = \frac{h \cdot \nu}{\sigma_0}$, ($\sigma_0 = \sigma_a + \sigma_e$, $h\nu$ - quantum of energy), E_0 is saturation energy density. Best fit of the data presented in Fig.12 by the expression (1) gives us E_0=5.5 10^{-3} J/cm^2, and σ_0=3.4 10^{-17} cm^2 . Solid curve in Fig.12 is calculated one with this value E_0. We know the ratio σ_a/σ_e from the data in Fig.1: σ_a/σ_e =2.8 so it is possible to calculate σ_a and σ_e separately: σ_a=0.9 10^{-17} cm^2 and σ_e=2.5 10^{-17} cm^2 (λ=1.064 μm). These cross sections are efficient cross sections. The structure of the centres wasn't taken into account here. Note that measured cross sections are approximately 1.7 less then represented in Fig.1, so according to our measurements all figures in Fig.1 should to multiply by coefficient 0.55 (shape and position of curves doesn't change). At wavelength λ=1.178 μm from Fig.1 taking into account the coefficient we have: E_0=5.1 10^{-3} J/cm^2 and σ_0=3.3 10^{-17} cm^2 (σ_a=0.02 10^{-17} cm^2 and σ_e=3.3 10^{-17} cm^2).

Now let us take into account that there are 6 possible orientations of the F_2^- centres in LiF. When electric vector of light is directed along [110] then transmission have to be calculated with the help of the expression

$$\frac{dx(z)}{dz} = -\alpha_1 \cdot \frac{1}{2}\left[(1 - e^{-x}) + 4 \cdot (1 - e^{-x/4})\right] - \alpha_2 \cdot x. \qquad (2)$$

Notation in (2) is the same as in (1) but E_0 is saturation energy density of a F_2^- centre when electric vector of light is parallel to line connecting centres of F vacancies. Using this expression from the data in Fig.12 we obtain: E_0=2.5 10^{-3} J/cm^2 , σ_0=7.4 10^{-17} cm^2, σ_a=1.9 10^{-17} cm^2 and σ_e=5.4 10^{-17} cm^2 (λ=1.064 μm).

4. Second harmonic experiments

In our SHG experiments we implemented LBO - crystal, NCPM, type 1. Parameters of the crystal are convinient for SHG. For example we take data from [8] for wavelengths in the vicinity of λ=1.178 μm (SHG, NCPM, type 1): temperature T=24.3 °C, λ=1.2 μm, T=61.1 °C,

1.15 μm. Estimation gives us the temperature 30 - 40 °C for λ=1.178 μm. Angular, temperature and spectral bandwidths values along X axis are highly noncritical [8].

Scheme of LiF: F_2^- in this case was almost the same as it is represented in Fig.5. but there were three prisms 7 (see Fig.5) for better spectral selection. Output energy was 0.1 mJ (0.5 mW at 5 Hz, 1.18 μm), pulse duration 80 ns, transverse distribution TEM_{00}. Spectral width was about 7 cm^{-1} (1.18 μm). In Fig.13 there is SHG - scheme: 1, 2 lens with focal length 10 cm each, 3 - LBO - crystal 4/4/10 mm, 4 - oven to maintain an appropriate temperature. Diameter of radiation at 1.18 μm in the LBO-crystal was 0.1 mm and maximum intensity of the radiation was about 10 MW/cm^2. LBO - crystal temperature was about 36° C. Efficiency of SHG 3% was achieved.

5. Heating of LiF:F_2^- under action of pump and generation radiation

Main feature of the active laser material LiF:F_2^- as at the pumping wavelength and at the wavelength of generation is high value of intensity of saturation $I_s=E_0/\tau$, where E_0 is saturation energy density and τ is a life time of the upper laser level. Estimation I_s gives us $I_s=10^5$ W/cm^2 (E_0=5.5 10^{-3} J/cm^2 (see above), τ=55 ns [2]) for the both pump and generation wavelengths. For the efficient transformation of pump radiation (1.064 μm) into the radiation of generation of F_2^- - cc (1.18 μm) it is necessary to ensure the intensity of radiation at the both wavelengths of the order of magnitude comparable to the intensity of saturation and there is no principle difference a generator or an amplifier is under consideration. As the intensity of saturation I_s is so high a problem of heat removing becomes important. Similar problem exists for cw dye lasers because I_s for a dye [9] is of the order of magnitude close to the one for F_2^- - cc. In the case of dye lasers the problem of heating was solved by moving of a dye solution and, thereunder, by the mechanical run out of heat from the area of generation. In our case this method can be realized by moving of a crystal with respect to an area of generation (or vice versa).

The importance of the LiF:F_2^- heating priblem can be clear seen from the fact that F_2^- - cc are bleaching at heating with activation energy 0.44 eV at temperature about 420 °K [7]. Let us evaluate change of temperature of LiF:F_2^- due to heating under the action of the both pump and generation radiation. We assume that passive losses at these wavelengths are equal. The crystals with the attitude of active and passive losses (contrast k ratio for passive Q-

switches $k = \frac{\ln(1/T_0)}{\ln(1/T_1)}$) k=5 are available at present. For an average heat power q per a volume unit of AE which is due to absorption of a radiation it is possible to write

$$q=2\gamma I_s \alpha/kd, \tag{3}$$

here α is an absorption coefficient of a pump radiation for a weak signal (α/k is passive losses), $2\gamma I_s$ is an intensity of radiation (pumping and generation); d is a duty factor. From (3) it is easy to obtain $q=2\ 10^4$ W/cm^3 at $\alpha=0.5$ cm^{-1}, k=5 (these values are common for LiF:F_2^-), d=10 (pulse duration is 100 μs and pulse repetition rate 1 kHz) and $\gamma=10$. It is possible to show that for a cylindrical AE with radius r_1 (see Fig.14) a difference of temperatures ΔT between its center and surface in a stationary case when heat is uniformly run out in the cylindrical area with radius r_0 coaxial to AE is given by the expession

$$\Delta T = \frac{q \cdot r_0^2}{4 \cdot \chi} \cdot (1 + 2 \cdot \ln(\frac{r_1}{r_0})), \tag{4}$$

where $\chi=0.12$ W/cm K is a thermal conductivity of LiF [10]. For a cilindrical AE with diameter 5 mm ($r_1=2.5$ mm), at $r_0=0.1$ mm, and $q=2\ 10^4$ W/cm^3 $\Delta T=31$ °C, e.g. for a forced cooling of a LiF:F_2^- (diameter 5 mm, length $l=1/\alpha=20$ mm), at average heat power 12 W, the temperature difference ΔT is about 30 °C. An average output power of generation can be estimated as $P=\gamma\ s\ I_s/d=30$ W, here s is a cross section area of a generation $s=3.1\ 10^{-4}$ cm^{-2} ($r_0=0.1$ mm). Average power of the pumping beam has to be approximately two - four times more then the generation power.

This is rather rough estimation but it gives us a sight into a problem of a cylinrical LiF:F_2^- - crystal heating (cooling). And we can say that it is possible in principle to reach average output power 10-30 W with cylindrical LiF:F_2^- - crystal under forced cooling at $\lambda=1.178$ μm. Transformation of the radiation into the second harmonic with the efficiency 20% will allow us to reach output power 2 - 6 W at the wavelength 0.589 μm. This evaluation shows that the scaling to higher output powers is problematical in this design. This conclusion will be more explicit if we take into account thermooptical distortions in LiF:F_2^- - crystal.

Let us now consider the case when the LiF:F_2^- crystal moves. In this case mechanical removing of heat from the area of generation is ensured. Let us assume that: 1) AE has a cylindrical form with the diameter r_1 , 2) AE rotates around its axis with a frequency f; 3) an area of generation is situated close to rim of the cylinder; 4) optical axis is parallel to a axis of the cylinder. The displacement of the crystal at distance $2r_0$ is necessary for a full removing of

the heat from an area of generation. At the repetition rate f_0=1 kHz it takes time $t_0=1/f_0$=1 ms for this displacement. That requires the velocity of motion $v=2r_0/t_0$ at the rotation frequency $f=v/2\pi r_1=f_0\, r_0/\pi r_1$. If we assume r_1=15 mm and r_0=0.1 mm (f_0=1 kHz) then v=20 cm/s and f=2 Hz. This value of f is low and construction difficulties are seemed solvable.

Let us evaluate heating of AE in this scheme. Pump radiation has repetition frequency f_0=1 kHz and each pulse has duration t_1=100 μs. It is possible to assume that the crystal doesn't move during time t_1. Changing of temperature ΔT under action of radiation during time t_1 is: $\Delta T= qt_1/c\rho$, where c and ρ are specific heat and density of a LiF crystal. In our conditions one can obtain: ΔT= 0.5 °C at $q=2\ 10^4$ W/cm^3 (c=1.6 J/g K, ρ=2.6 g/cm^3 [10]).

Having this value of ΔT we can make the density of the pump power (and accordingly the generation one) minimum 10 times more. Thereby there is a principal possibility to reach output power at the wavelength 1.178 μm 50 - 100 W and at the wavelength 0.589 μm - 25 - 50 W. Technically air cooling of revolving AE will not present difficulties as its surface is large (about 30 cm^2 at length of the crystal 30 mm). Note also, that we can expect that thermooptical distortions in this case will be substantially less than in the preceding one.

As the result of our evaluations we come to conclusion that implementation of the moving AE scheme gives us a possibility of scaling of the laser system from low to high average output powers. Traditional scheme of cylindrical AE with forced cooling has some difficulties when scaling to high (50 - 100 W at λ=1.178 μm) output powers. Note that the scheme of moving AE in solid state lasers has been suggested and realised (see for example [11]).

It is necessary more detailed design of parts and calculation of operation conditions of the laser under consideration for its technical realization.

6. Conclusion

1. Generation characteristics of a LiF:F_2^- - laser have been investigated for both short and long pump pulses and different configurations of the laser resonator. For short pump pulse (70 ns - 100 ns) at λ=1.178 μm the slope efficiency was 10.7 %, threshold energy 0.56 mJ, overall efficiency 9.4%. For long pump pulse (about 100 μs, free running mode, spikes) threshold 72 W has been achieved.

2. Experiments have shown that there are lens in a LiF:F_2^- active element which is due to pumping and its nature most probably is not thermal. More experiments are needed to clear the question.

3. Saturation energy density E_0 at λ=1.064 μm has been measured: E_0=5.5 10^{-3} J/cm^2. Efficient cross sections of absorption and emission have been calculated: σ_0=3.4 10^{-17} cm^2, σ_a=0.9 10^{-17} cm^2 and σ_e=2.5 10^{-17} cm^2 (λ=1.064 μm, structure of the cc was not taken into account).

4. SHG experiments were made with LBO-crystal (NCPM, type 1) at pulse duration about 80 ns (0.1 mJ, 1200 W, λ=1.18 μm, $\Delta\nu$=7 cm^{-1}) and conversion efficiency 3 % has been achieved.

5. Two possible heat removing alternative designs of a LiF:F_2^- - crystal have been considered. The first one is a forced cooling cylindrical AE. Calculation of temperature distibution in AE has shown that for this scheme it is possible to reach awerage output power 2 - 6 W at λ=0.589 μm, but scaling to higher poweres for this design is problematical. The second design is moving LiF:F_2^- - crystal. In this case evaluations have shown that it is possible to obtain average output powers 25 - 50 W at 0.589 μm and this is not limit because it is possible to scale the sistem to higher values of output powers.

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12 May 1998

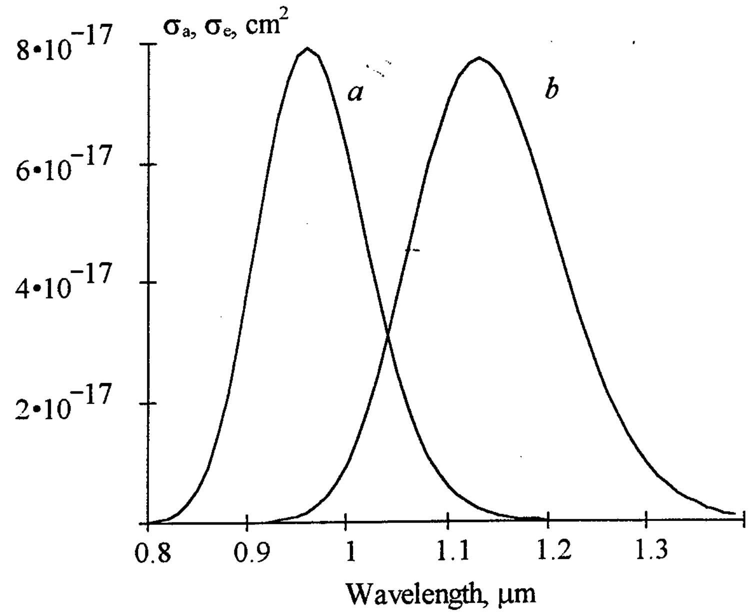

Fig.1. Absorption σ_a (*a*) and emission σ_e (*b*) cross sections of F_2^- - cc in LiF [2, 3].

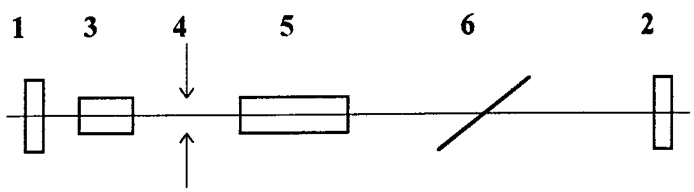

Fig. 2. Layout of YAG:Nd laser with LiF: F_2^- crystal passive Q-switch.

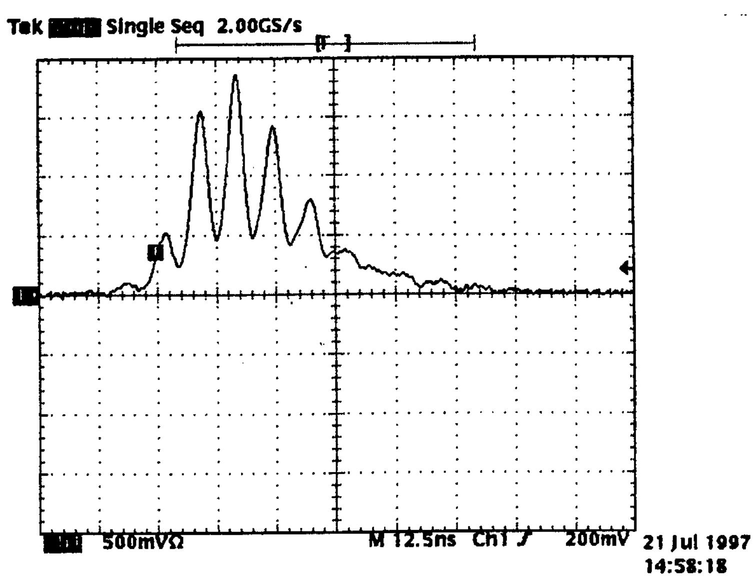

Fig. 3. Oscillogram of output pulse

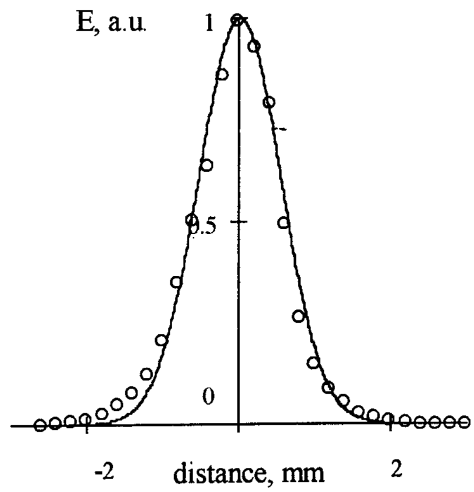

Fig. 4. Transverse distribution of the output beam energy.

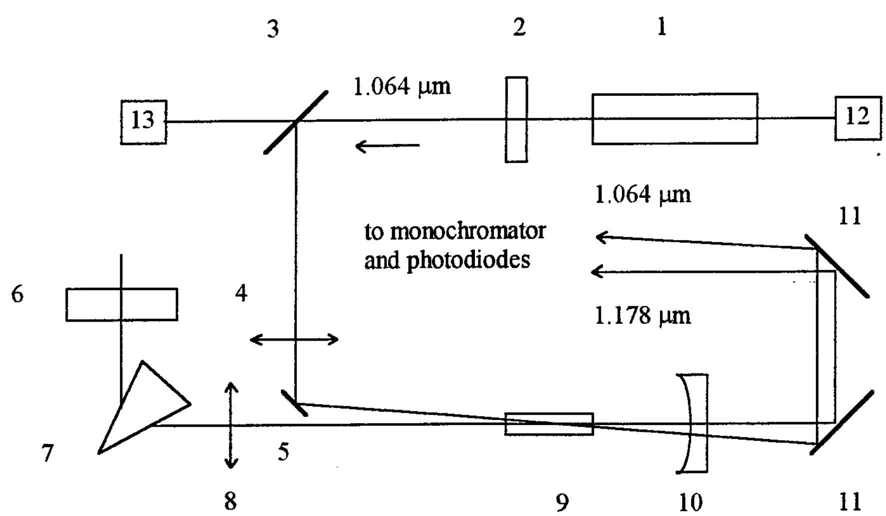

Fig. 5. Layout of LiF:F_2^- laser; uncollinear scheme of pumping.

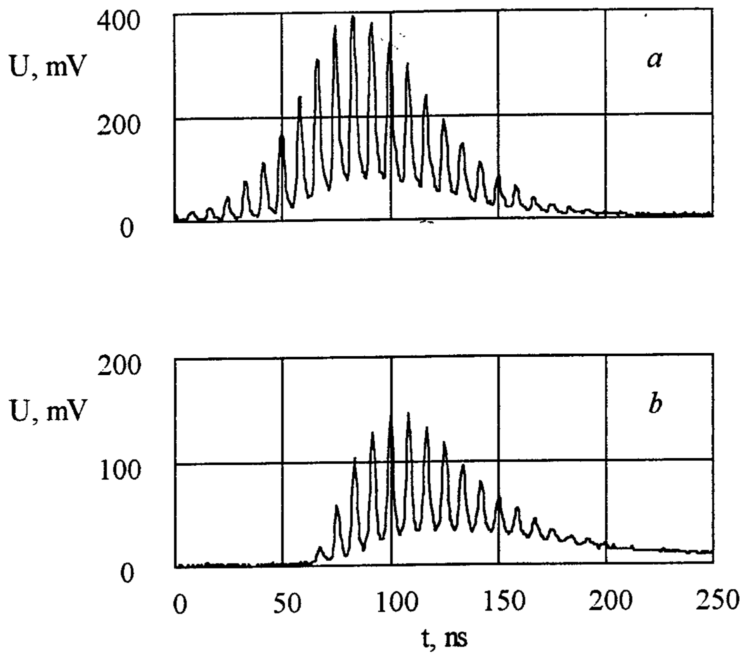

Fig. 6. Oscilloscope traces of pump beam (*a*) and LiF:F_2^- laser generation at 1.178 μm (*b*).

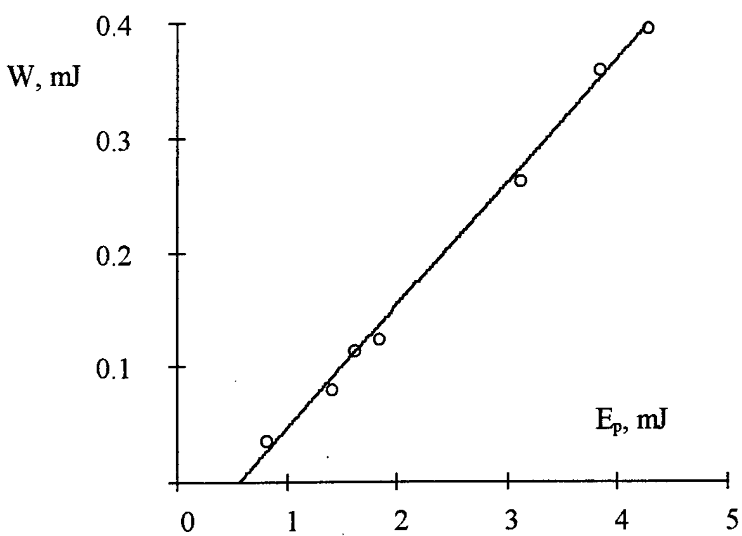

Fig. 7. Output pulse energy of LiF: F_2^- laser at 1.178 μm as function of pump pulse energy.

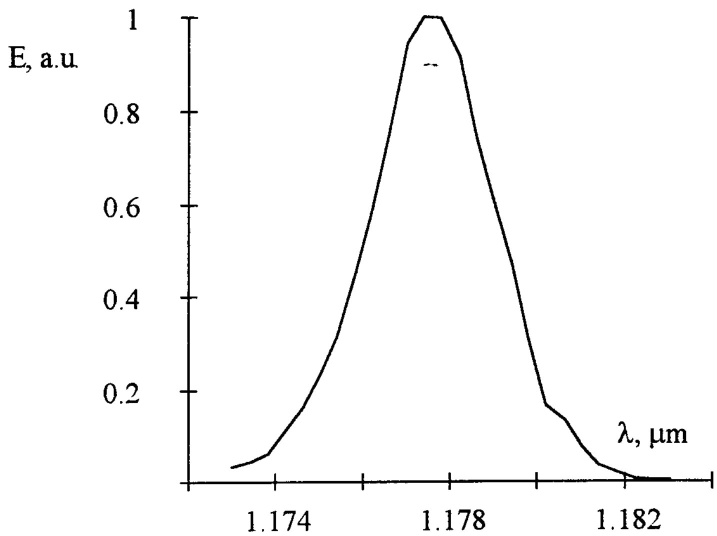

Fig. 8. Spectrum of LiF: F_2^- laser at pump pulse energy 4.5 mJ.

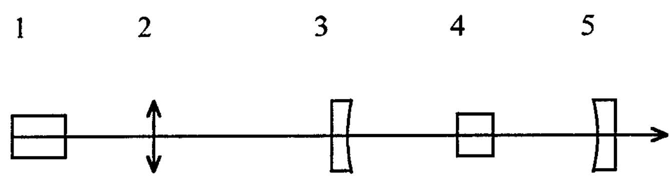

Fig. 9. Long a pulse pumping experiment layout.

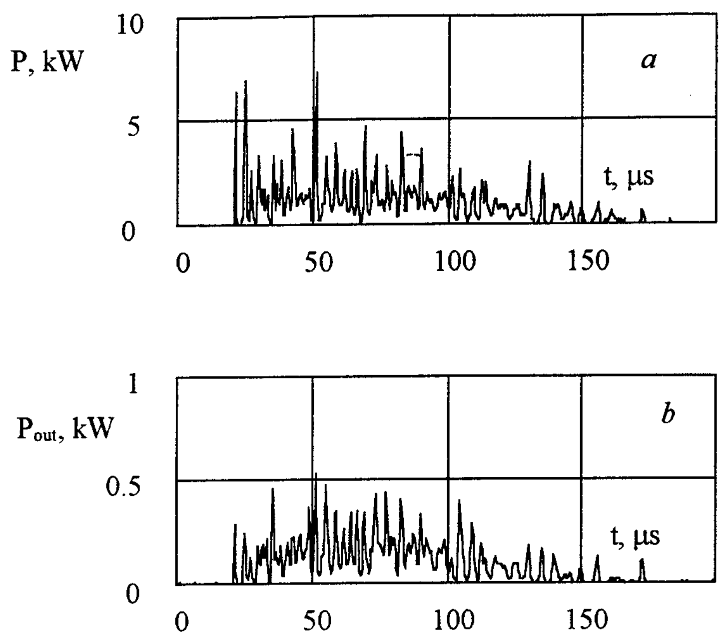

Fig. 10. Pump(a) and output of LiF: F_2^- laser (b) powers as function of time (free running mode).

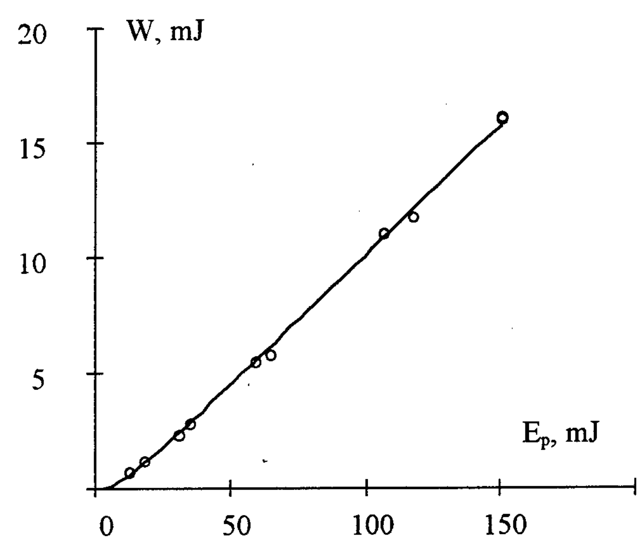

Fig. 11. Output energy W of LiF: F_2^- laser at 1.18 μm as function of pump energy E_p for a long pulse pumping. Solid curve is calculated.

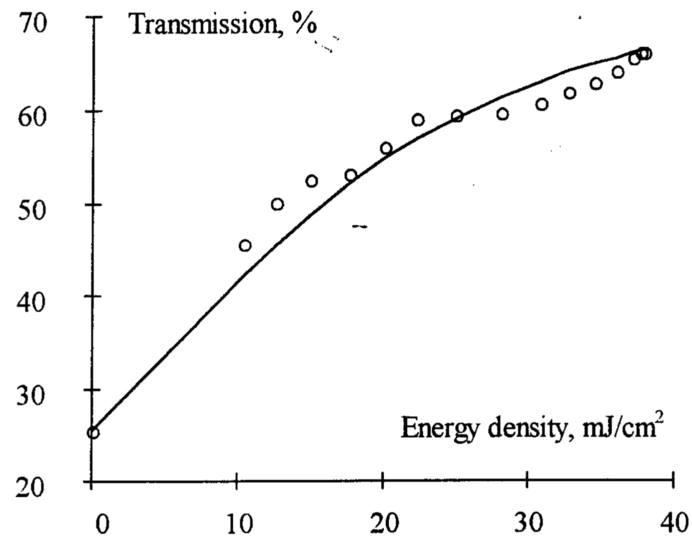

Fig.12. Transmission of LiF:F_2^- - crystal as function of energy density . LiF:F_2^- - crystal characteristics: T_0=25.5%, T_1=81.4%, crystal length - 39 mm.

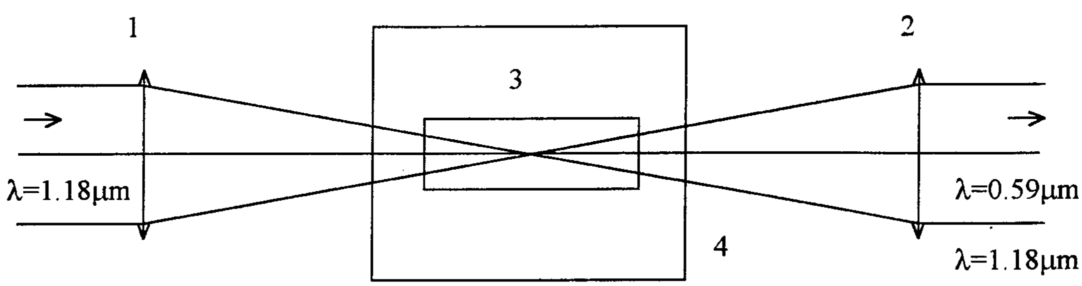

Fig.13. SHG scheme.

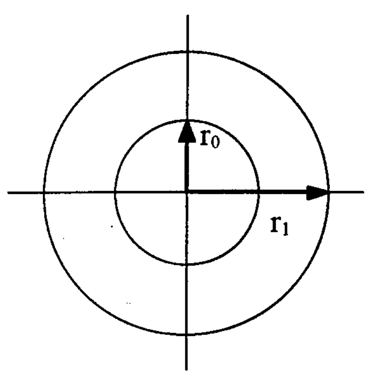

Fig.14. Scheme of a cylindrical LiF:F_2^- - crystal heating. AE has radius r_1 and heat is uniformly run out in an area with radius r_0, cylindrical symmetry.